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DETERMINING BASIC WIND LOADS

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STRUCTURAL DIVISION

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DETERMINING BASIC WIND LOADS

George F. Collins[a]

THEORY

In recent years and particularly since early in 1952, several articles pertaining to winds as design factors have appeared in the engineering literature.* During 1952-1953 the writer conducted an independent study to determine a reasonable basic wind load at various places throughout the United States. Since this work closely parallels that of other investigators, the final results are offered here for comparison, and a simple method is outlined for determining basic wind loads. In this study, basic wind load is defined as the probable maximum velocity pressure to be expected on a flat surface normal to the wind for a given location and elevation. The corrections necessary due to a structure's shape or mass are not considered as part of the study.

Long-term wind records are available from some 200-odd United States Weather Bureau stations throughout the country.[1] Unfortunately, these records cannot be used directly to compute wind load without (1) converting the wind at the level of the anemometer to the elevation in which we are interested, and (2) determining peak winds or gusts to be expected when the mean wind over a given time interval is given. (Most records give the mean 5-minute wind. Only at some of the stations are instruments available which register peak gusts.) There is considerable disagreement among the various investigators regarding the computation of actual velocity pressures at different elevations from the wind records available. Hence, this study was undertaken.

When selecting a design wind for a given location, either the greatest wind on record or the most probable wind occurring once in a given number of years can be used. The latter can be obtained from a statistical curve such as shown in Fig. 1, and design can then be made with a known risk. (Tabulations of maximum 5-minute mean winds for each year of record are obtainable from IBM punch cards at the National Weather Records Center, Asheville, North Carolina.)

In an attempt to place gust factors (i.e.—ratio of peak gust to mean 5-minute wind) and wind variation with elevation on a similar probability basis, wind records from meteorological towers at Hanford Engineer Works, Richland, Wash. and Brookhaven National Laboratory, Upton, Long Island, N. Y., were analyzed. Records such as shown in Fig. 2 (made by Bendix-Friez "Aerovanes") were available from elevations ranging from 7 ft. to 410 ft. above grade. Both towers are located on flat terrain but one is a considerable distance inland beyond a mountain barrier, while the other is often exposed to winds direct from the sea. Nine different storms were analyzed for gust factors and wind speed variation with height. One additional record from a tower at the University of Akron[2] at Tallmadge, Ohio, was used as a check only for determining variation of wind speed with elevation.

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*See references 2 through 11.

Gust factors were obtained by placing a transparent grid over the wind trace and visually checking the ratio of peak gusts to mean 5-minute winds. Since the response time of "Aerovanes" at high wind speeds is less than 2 seconds, it is felt that, for all practical purposes, the peak gusts that would affect a building were recorded. Gust factors were then grouped for both locations according to elevation and to wind speed ranges and the following results obtained:

1) Gust factors decreased with increasing wind speed. (Gust factors that were not exceeded 99% of the time are shown in Fig. 3.
2) There was no dependent relationship evident between elevation and gust factor other than that wind speed increases with elevation and, hence, gust factors tended to decrease.
3) Results at both Brookhaven and Hanford were identical, indicating that for high winds the wind variations with elevation are similar.

Several different formulas have been put forth to describe the variation of wind speed with elevation above grade. The one in most common usage is $V_2 = V_1 \times \frac{H_2}{H_1}^a$, where V_1 and V_2 are the wind speeds at heights H_1 and H_2, respectively, and "a" is a constant dependent upon atmospheric turbulence. Sherlock[3] presents evidence for a value of 1/7 (or 0.143) for "a". This value had previously been advocated by O. G. Sutton[4] for average conditions. On more of the storms studied by the writer, however, did this value give a satisfactory fit (Fig. 4). Other investigators have experienced similar difficulty and have suggested values ranging from 0.1 to 0.4. The best fit to the observed velocity profile of a tropical storm at Brookhaven on November 25, 1950,[5] was 0.25. Hellermann[6] has prepared a table of values ranging from 0.2 to 0.4, depending upon the surface roughness of the terrain and suggests the value of 0.33 for most city areas.

The writer submits here, however, a varying set of profiles based on an increase in value of "a" with increasing winds as follows:

Average Wind at 30 ft.	"a"
10 m.p.h.	0.19
20 m.p.h.	0.21
30 m.p.h.	0.23
40 m.p.h.	0.25
50 m.p.h.	0.27
60 m.p.h.	0.29
70 m.p.h.	0.31

Fig. 5 has been drawn by assuming a 30-ft. wind and then computing the wind at 400 ft. from the above values of "a". Intermediate winds are found along the logarithmic line connecting the 30-and 400-ft. points. Application of these velocity profiles to the ten storms studied gave excellent results, while the 0.143 value gave considerable error. Computed profiles were drawn from Fig. 5 for each storm and standard deviations (σ) from the actual profile were tabulated for ten different elevations. For the storms studied, 3σ had the value of 3.78 m.p.h. This means that we can safely say that 99.7% of the time the error was within the limits of $\pm$ 3.78 m.p.h. One case involving the 0.143 power gave winds 18 m.p.h. too low.

Spot checks using other high wind observations indicate that the velocity profiles developed here are equally as accurate as methods now in common use, and in some instances are more accurate. It is of interest to note that

the United States Weather Bureau gives the maximum 5-minute mean wind of record for Miami, Florida, as 87 m.p.h. at an elevation of 79 ft. (1926 hurricane). From structural damage done to a penthouse on top of a 17-story building (approximately 200 ft. elevation) during this storm, it is estimated that the total wind force must have been 65 lb./sq. ft.[7] The velocity pressure obtained from Fig. 5 using the Weather Bureau wind record is 60 lb./sq.ft. at 200 ft. If the usual shape factor of 1.2 is assumed for a rectangular structure, the total wind pressure would have been 1.2 x 60 or 72 lb./sq.ft.

Records of the 1935 hurricane made on a gust recording type anemometer by independent observers atop a 230-ft. building in Miami have recorded mean winds of about 120 m.p.h. with peaks well over 150 m.p.h. Using the official wind record at Miami for 1926, a mean 5-minute wind of 118 m.p.h. would have been anticipated from Fig. 5 for the 230 ft. level. Peak gusts of 170 m.p.h. would have been indicated. This corresponds to a velocity pressure of 67 lb./sq.ft. which is comparable with design figures of 60 to 70 lb./sq.ft. now being employed in the Florida area to the design of radio towers and other tall structures.

Application

Once the appropriate gust factors and variation of wind speed with elevation have been determined, the basic problem becomes one of selecting a proper design wind. Both official and non-official sources should be carefully studied to determine which are the most representative for the area in question. Such factors as exposure of instruments and type of terrain must be considered. Statistical studies should be made, if possible, to determine the probability of occurrence of a very high wind. After the design wind for a given location has been chosen, the velocity pressure can then be computed as follows:

$$\text{Velocity Pressure} = \frac{mV^2}{2} \quad \text{or} \quad \rho\frac{(KV)^2}{2g}.$$

Where K is the gust factor, ρ is density of air, g is 32.2 ft./sec./sec. and V is wind speed in ft./sec. Density of air is taken as 0.08 lb./cu.ft. (density at 32°F) in this study as many storms occur at temperatures around freezing. This value would be conservative for storms of tropical origin.

Fig. 5, the end product of this investigation, shows the variation of wind with elevation and its corresponding velocity pressure. In computing velocity pressure, the appropriate gust factor of Fig. 3 has been employed. Knowing the anemometer wind, it is a simple matter to determine the velocity pressure at any elevation as is shown by the following example:

Location: Buffalo, New York
Height of Anemometer: 280 ft.
Design to be made for the once in 20-year storm.
Wanted: A. Velocity pressure at the top of a 150 ft. stack
B. Velocity pressure on a 30 ft. warehouse

Wind at anemometer level for the once in twenty year storm (5% line, or 72 m.p.h.) is determined from Fig. 1. From Fig. 5 we obtain:

Elevation	Wind	Velocity Pressure
30 ft.	41 m.p.h.	10 lb./sq.ft.
150 ft.	65 m.p.h.	21 lb./sq.ft.

SUMMARY

This study does not propose to be a final solution to the problem of determining basic wind loads. It has been shown, however, that the use of the conventional 1/7th power law could lead to considerable error in the design of tall structures. On the other hand, the same law may lead to over design for low structures. There are certain limitations and shortcomings to the method proposed here, a few of which are listed below:

1. The method gives only the probable maximum velocity pressure at a point. It does not consider the combined effect of gusts over the entire elevation of a structure.
2. More data for extremely high winds are desirable, particularly two or more records at different elevations on the same tower to further check gust factors and variations of wind with elevation.
3. Reliable wind data may not be available for a desired location. Wind load computations will depend upon the judgment exercised in selecting a representative design wind.

ACKNOWLEDGMENTS

The writer wishes to thank Brookhaven National Laboratory and Hanford Engineer Works for supplying the basic data for this study.

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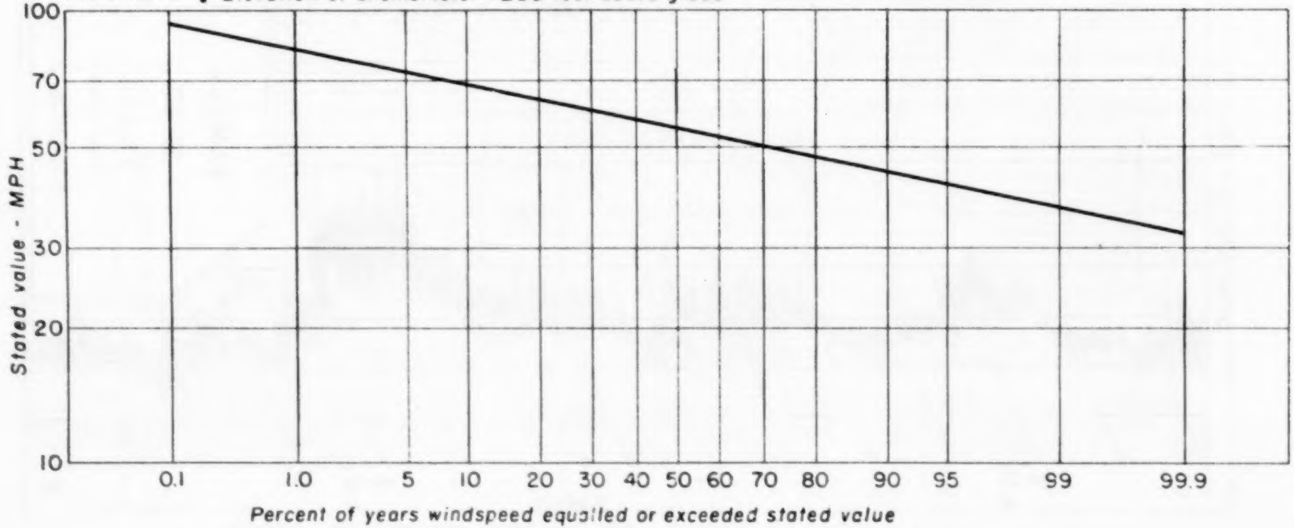
MAXIMUM 5-MINUTE MEAN WINDS OF RECORD FOR SELECTED UNITED STATES WEATHER BUREAU STATIONS

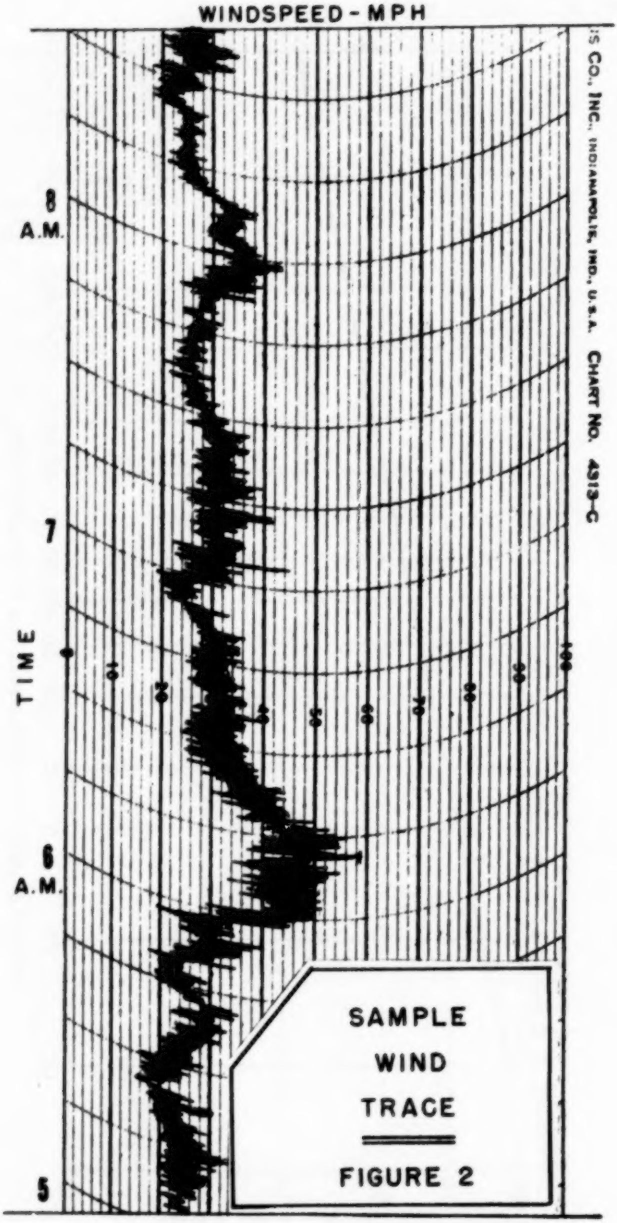
Location	Years of Record	Anemometer Elevation Above Ground	Maximum 5-Min. Wind Of Record
Abilene, Texas	62 years	70 ft.	57 m.p.h.
Albany, New York	74	48	59
Albuquerque, New Mexico	17	45	68
Amarillo, Texas	56	61	70
Apalachicola, Florida	25	49	55
Atlanta, Georgia	69	72	53
Atlantic City, New Jersey	74	172	91
Baltimore, Maryland	76	117	54
Binghamton, New York	51	79	38
Birmingham, Alabama	44	144	47
Bismarck, North Dakota	73	43	61
Boise, Idaho	62	49	56
Boston, Massachusetts	75	62	73
Brownsville, Texas	29	96	80
Buffalo, New York	75	280	73
Burlington, Vermont	42	48	54
Charlotte, North Carolina	69	161	56
Cheyenne, Wyoming	75	101	65
Chicago, Illinois	76	274	65
Cincinnati, Ohio	78	51	43
Cleveland, Ohio	75	318	61
Columbia, South Carolina	47	57	49
Columbus, Ohio	69	222	60
Dallas, Texas	34	227	68
Davenport, Iowa	77	54	52
Denver, Colorado	75	151	53
Des Moines, Iowa	69	88	50
Detroit, Michigan	77	258	67
Dodge City, Kansas	73	86	65
Duluth, Minnesota	75	47	68
Elkins, West Virginia	49	67	43
El Paso, Texas	70	110	60
Erie, Pennsylvania	74	166	55
Escanaba, Michigan	56	60	45
Eureka, California	61	89	46
Evansville, Indiana	50	175	60
Fort Smith, Arkansas	66	94	57
Fort Wayne, Indiana	37	33	53
Fresno, California	60	98	41
Galveston, Texas	77	114	71

Location	Years of Record	Anemometer Elevation Above Ground	Maximum 5-Min. Wind Of Record
Grand Haven, Michigan	59 years	89 ft.	56 m.p.h.
Harrisburg, Pennsylvania	60	104	56
Havre, Montana	67	44	57
Helena, Montana	68	113	56
Houston, Texas	37	314	63
Huron, South Dakota	67	41	63
Indianapolis, Indiana	77	230	63
Jacksonville, Florida	76	129	58
Kansas City, Missouri	60	76	63
Knoxville, Tennessee	77	51	59
Lander, Wyoming	55	68	60
Little Rock, Arkansas	69	147	49
Los Angeles, California	71	250	43
Louisville, Kentucky	75	124	58
Lynchburg, Virginia	72	188	49
Madison, Wisconsin	43	38	56
Medford, Oregon	8	58	42
Memphis, Tennessee	75	154	58
Meridian, Mississippi	55	92	40
Miami, Florida	37	79	87
Minneapolis, Minnesota	52	208	65
Mobile, Alabama	77	161	87
Missoula, Montana	9	91	43
Montgomery, Alabama	75	112	43
Moorhead (Fargo, North Dakota), Minnesota	63	43	55
Nashville, Tennessee	77	96	58
New Haven, Connecticut	75	153	49
New Orleans, Louisiana	75	84	66
New York, New York	76	454	81
Norfolk, Virginia	76	205	63
North Platte, Nebraska	73	71	73
Oklahoma City, Oklahoma	57	47	57
Omaha, Nebraska	75	44	73
Philadelphia, Pennsylvania	77	367	68
Phoenix, Arizona	52	82	41
Pittsburgh, Pennsylvania	75	410	56
Portland, Maine	76	117	50
Portland, Oregon	76	209	43
Raleigh, North Carolina	61	69	56
Rapid City, South Dakota	60	63	67

Location	Years of Record	Anemometer Elevation Above Ground	Maximum 5-Min. Wind Of Record
Reno, Nevada	48 years	50 ft.	59 m.p.h.
Richmond, Virginia	50	52	63
Roswell, New Mexico	43	75	50
St. Louis, Missouri	75	210	62
Salt Lake City, Utah	74	46	60
San Antonio, Texas	69	301	56
San Diego, California	75	55	44
San Francisco, California	77	243	50
Savannah, Georgia	77	152	73
Seattle, Washington	54	321	59
Sheridan, Wyoming	40	38	66
Shreveport, Louisiana	76	227	52
Spokane, Washington	67	44	42
Springfield, Missouri	62	104	52
Syracuse, New York	65	113	56
Tampa, Florida	58	197	75
Vicksburg, Mississippi	76	74	49
Washington, D. C.	77	85	53
Wichita, Kansas	60	158	68
Wilmington, North Carolina	77	65	65

FIGURE 1 **BUFFALO, NEW YORK · PROBABLE MAXIMUM 5-MINUTE WIND SPEED**
Elevation of anemometer = 280 feet above grade





SAMPLE
WIND
TRACE

FIGURE 2

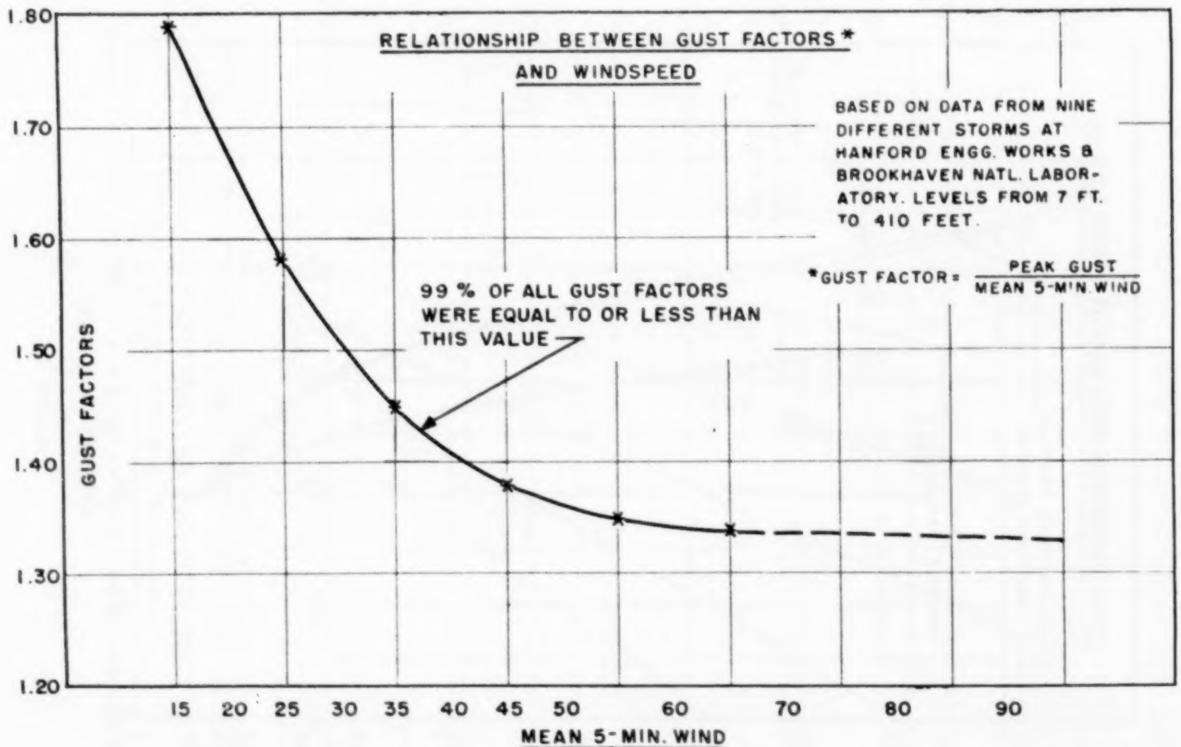
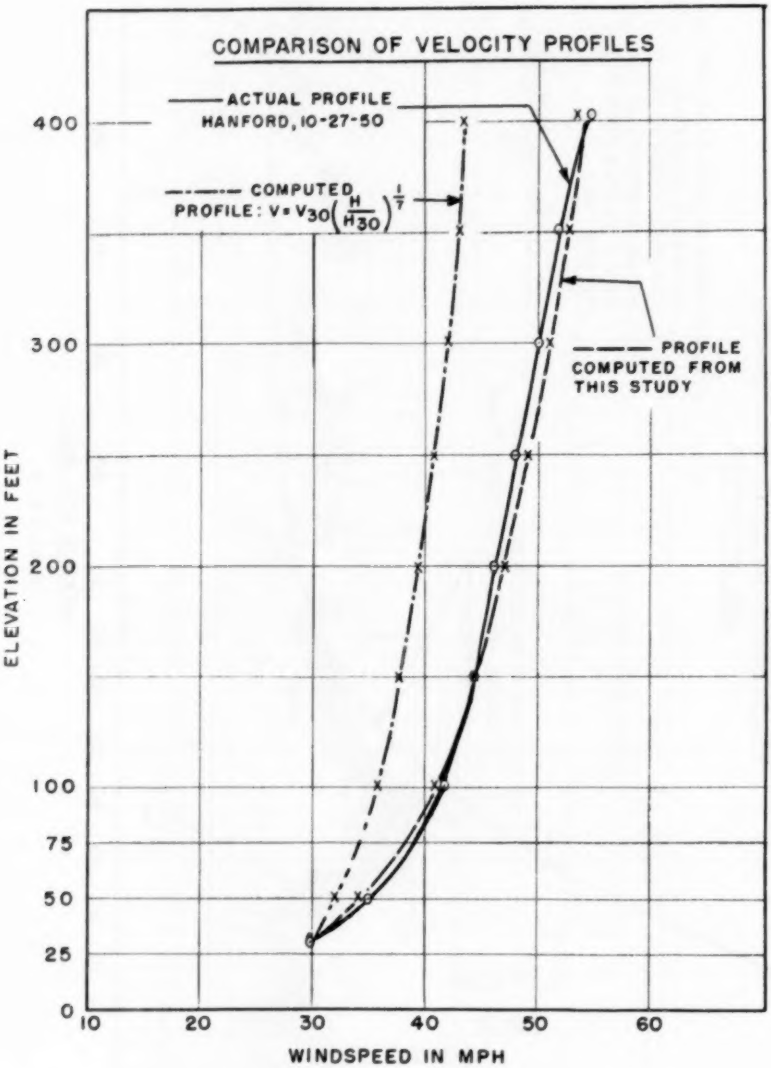

RELATIONSHIP BETWEEN GUST FACTORS*
AND WINDSPEED
BASED ON DATA FROM NINE DIFFERENT STORMS AT HANFORD ENGG. WORKS & BROOKHAVEN NATL. LABORATORY. LEVELS FROM 7 FT. TO 410 FEET.
*GUST FACTOR = PEAK GUST / MEAN 5-MIN. WIND
99 % OF ALL GUST FACTORS WERE EQUAL TO OR LESS THAN THIS VALUE
GUST FACTORS
1.80
1.70
1.60
1.50
1.40
1.30
1.20
15
20
25
30
35
40
45
50
60
70
80
90
MEAN 5-MIN. WIND

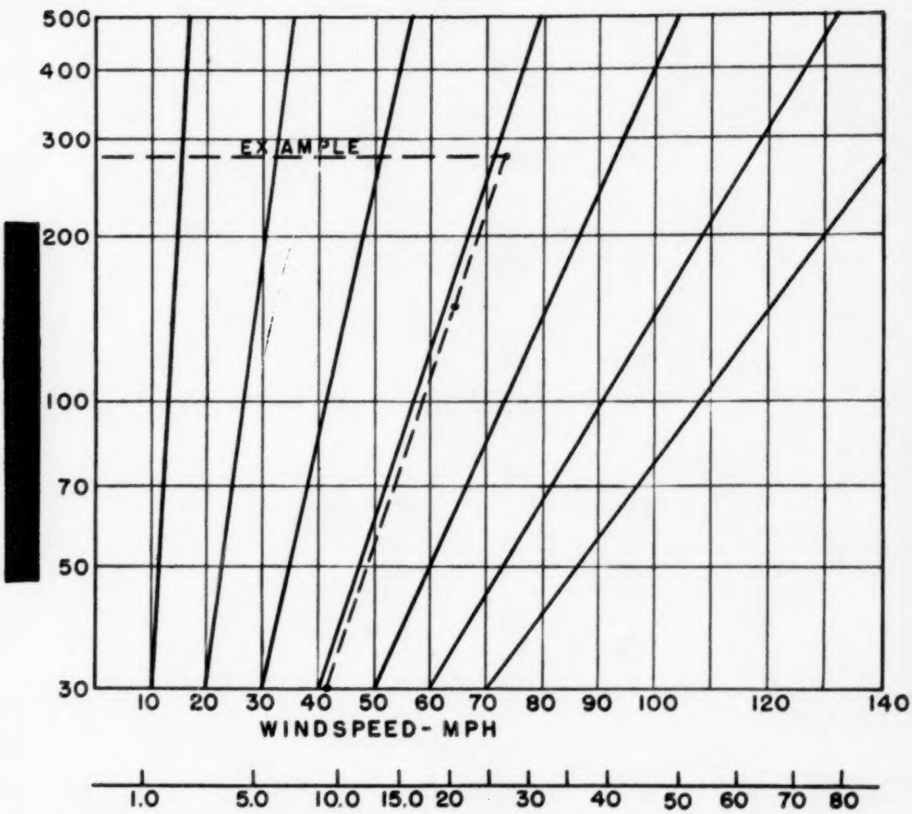
FIGURE 3



COMPARISON OF VELOCITY PROFILES
ACTUAL PROFILE
HANFORD, 10-27-50
COMPUTED
PROFILE: $V = V_{30}\left(\frac{H}{H_{30}}\right)^{\frac{1}{7}}$
PROFILE
COMPUTED FROM
THIS STUDY
ELEVATION IN FEET
400
300
200
100
75
50
25
0
10
20
30
40
50
60
WINDSPEED IN MPH

FIGURE 4

WINDSPEED & VELOCITY PRESSURE



VELOCITY PRESSURE - LBS. PER SQ. FT. ON FLAT SURFACE NORMAL TO WIND

(GUST FACTOR INCLUDED - AIR DENSITY TAKEN AS 0.08 LB. PER CU. FT.)

FIGURE 5

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